FARADAY
TECHNOLOGY, INC.

Pulse Reverse Current Surface Finishing for Plating on Passive Surfaces

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Challenge

- **Goal:** Develop *Environmentally Benign Electrochemical* Surface Treatment Techniques to enable direct deposition onto a range of passive alloys
 - Al Alloys (6061/ 7075)
 - Ti Alloys (Ti64/Ti)
 - Nb/Ta
- Common Coatings for wear resistance and improved surface hardness:
 - Ni
 - NiB
 - NiP
 - Pt
- *Keys to success:*
 - Elimination of number of processing steps
 - Use of hazardous chemicals

Systems Evaluated at Faraday

- **ZnNi for Cd replacement on Al 6061 Electrical connectors**
- **Ni and NiP for EN replacement on Al 6061 Neutrino Horns**

<http://jclub.chess.cornell.edu/papers/Magnetic%20focusing%20Horns%20for%20neutrino%20experiments.pdf>

Standard Approach to Deposition onto Al

- Typical electroless nickel process on 6061 Al:

- ~16 Step process!!!
- Each of these steps takes high volumes of consumable chemistries
 - Some of which contain worker hazardous chemistries.
- If any of the steps completed inadequately all steps must be repeated

Targeted Process

Electrochemical Pretreatment

PROCESS STEPS

1

2

FARADAYIC®
Pretreatment

Rinse
(2 tanks)

Anodic pulse "tuned":

- Control current distribution
- Enable aqueous processing

Off-time "tuned":

- Replenish reacting species
- Remove reaction products
- Heat dissipation

Cathodic pulse "tuned":

- Depassivate surface/oxide removal
- Eliminates need for toxic species like HF

Electrodeposition

3

4

5

FARADAYIC®
ElectroDeposition
of Nickel @ Room
Temperature

Rinse
(2 tanks)

Dry

Cathodic pulse "tuned":

- Enhance mass transfer
- Control current distribution
- Control nucleation

Off-time "tuned":

- Replenish reacting species
- Remove reaction products
- Heat dissipation

Anodic pulse "tuned":

- Remove H₂ effects
- Control pH
- Leveling

Potential 5 Step Process

E.J. Taylor "Adventures in Pulse/Pulse Reverse Electrolytic Processes: Explorations and Applications in Surface Finishing" J. Appl. Sur. Fin. 3(4) 178-89 (2008).

FARADAYIC® Pretreatment Development (ZnNi)

Pretreatment Trials For Direct DC deposition (ZnNi) onto Al 6061

Visual Exam: **Fail**

Pass

Trial 1

Grit blast
Scotch Brite

Trial 2

Grit blast
Scotch Brite
Acid etch

Trial 3

Grit blast
Scotch Brite
Ni Strike

Trial 4

Grit blast
Alkaline etch
Scotch Brite

Trial 5

Alkaline etch
Scotch Brite

Trial 6

FARADAYIC®
ElectroPretreatment

Faraday's approach is the only non-contact, single step, and grit media free technique

FARADAYIC® Pretreatment Development

- FARADAYIC® Pretreatment Electrolyte Evaluation
 - Investigated a range of electrolytes (Basic, Neutral, Acidic)
 - Selected a electrolyte with 10% H_2SO_4
- FARADAYIC® Pretreatment Parameters
 - Anodic on time to off time ratios
 - Cathodic on time to off time ratios
 - Anodic to cathodic voltage ratios
 - Process time

Experiment Setup

Pretreatment Cell

(30 L)

Ni/NiP

Ni/NiP Plating Cell (35 L)

ZnNi

60 Gal

FARADAYIC® ElectroDeposition Development

- FARADAYIC® ElectroDeposition Electrolyte
 - Dipsol 1Z-C17+ Alkaline ZnNi
 - Watts Nickel electrodeposition electrolyte
 - Umicore NIPHOS_968 (NiP)
- FARADAYIC® ElectroDeposition Parameters
 - Cathodic on time to off time
 - Plating time
- Demonstrated FARADAYIC® ElectroDeposition on a range of geometries

Testing And Characterization

- Current Planned Tests that have been or will be performed, include:
 - ✓ Visual examination
 - ✓ Surface roughness (optical / contact profilometry)
 - ✓ Consistency through thermal variations (100 °C, 1hr)
 - ✓ Thermal Stress Test
 - ✓ Bend Test
 - ✓ Coating thickness (cross section)
 - ✓ Coating hardness (microhardness, cross section)
 - ✓ Coating adhesion (bend test, ASTM D 3359 tape test)
 - ✓ Wear resistance (ASTM D4060)
 - ✓ Corrosion resistance (MIL-A-8625F)
- Radiation test (beam line) (Currently in Line)

Material Characterization

Post 100°C for 1 h

Label	Thickness, μm	Microhardness, hv	Ra, μm	SEM-EDX, wt%	
				Ni	P
EN	23	~500*	0.24 ± 0.06	89.3	10.7
NiP1	40		0.26 ± 0.04	87.9	10.8
NiP2	16		0.26 ± 0.04	87.9	10.8
NiP3	48	526	0.26 ± 0.04	87.9	10.8

Both Electroless Nickel-P (EN 1) and FARADAYIC® NiP (NiP 1-3) coupons showed similar microhardness, microstructure, Ra, and composition

*Microhardness value for EN coating
<https://advancedplatingtech.com/electroless-nickel/electroless-nickel-phosphorus-content/>

Thermal Test Of Ni Or NiP On Al 6061

Thermal (100 °C, held for 1 hr)

Nickel

Nickel Phosphorus

Both Electroless Nickel-P (EN1, 2) and FARADAYIC® ElectroDeposited Nickel (Ni1, 2) coupons **passed Thermal test**

Bend to Break Test Of Ni On Al 6061

Bend Test 0.5" Mandrel

Bend testing was performed with a 0.5" bend radius 1" x 4" panels at FermiLab.

Electroless Nickel-P, FARADAYIC® Ni, and FARADAYIC® NiP and (NiP 96-107) coupons **passed Bend to Break** as measured at FermiLab

1" x 4" x 0.1"
Electroless NiP
on 6061 Al

1" x 4" x 0.1"
FARADAYIC®
Electrodeposited Ni
on 6061 Al

1" x 4" x 0.1"
FARADAYIC®
Electrodeposited NiP
on 6061 Al

Wear Resistant (ASTM D4060)

Test Date	06/11/2019
Temperature (F)	70.7
Humidity (%RH)	63%
Abrading Counterweight	750 g
Speed Control	60 RPM
Vacuum Power	100%
Abrading Disc Type	CS-10
Recondition Frequency	500 Cycles

Coupon Identifier	Thickness, μm	Wear Index @ Failure Cycles, mg/1000 cycle
EN1	23	23.6
96	21	22.7
101	15	23.2
102	18	39.6
107	18	22.9

Both Electroless Nickel-P (EN1) and FARADAYIC® NiP (NiP 96-107) coupons **showed similar wear index number** as measured at FermiLab

Corrosion Resistance NiP EP onto 6061 (MIL-A-8625F)

Post 336h salt fog test

15 sq inch per coupon	Coupon Label	Plating Waveform	Thickness, μm	Number of Pits	Corrosion Test Time (h)
Electroless Nickel (EN)	EN7	Standard EN Process	~23	0	336
	EN8		~23	0	336
	EN9		~23	0	336
	EN10		~23	0	336
FARADAYIC® NiP Electrodeposition	106	DC	15	0	336
	108	DC	19	0	336
	109	DC	17	0	336
	110	DC	21	0	336
	111	DC	25	0	336
	113	DC	20	0	336
	114	DC	24	0	336
	115	DC	17	1	336
	118	DC	21	0	336
	119	DC	23	0	336

Both Electroless Nickel (EN7-10) and FARADAYIC® NiP (NiP106-119) coupons **passed 336h corrosion test** MIL-A-8625F

Electroless Nickel

FARADAYIC® NiP

Corrosion Resistance Ni EP onto 6061 (MIL-A-8625F)

Electroless Ni-P
Plating

As-Plated

Post 352 h Salt Fog Test (per MIL-A-8625F)

- Electroless nickel-phosphorus passed the corrosion test
- FARADAYIC® Electrodeposition of Ni showed the potential to pass the corrosion test

Corrosion Resistance ZnNi EP onto 6061 (MIL-A-8625F)

DC

Pulse

96 h

6061	96 h			
%	DC	DC Conversion Coating	Pulse	Pulse conversion coating
Good	0	25	0	87.5
Blistering	60	37.5	92.5	7.5
Exposed Substrate	40	37.5	7.5	5

- Pulse waveform coating and conversion coating shows better performance in corrosion resistance after 96 hours salt fog test

Process Comparison/ Econ

Conventional Electroless Nickel-P Pretreatment/Plating Line

FARADAYIC® Pretreatment/Plating Line

Summary Of Results To Date

- Demonstrated a scalable **5-step** FARADAYIC® Pretreatment & ElectroDeposition process *to* replace the **16-step** electroless nickel process

- Demonstrated potential to **match and exceed the performance** of the electroless nickel-phosphorus coating
- Improved **electrodeposition rate from 10 to 23 $\mu\text{m}/\text{h}$** when compared to electroless nickel-phosphorus deposition
- Showed the potential for **at least 50% cost saving** when compared to conventional electroless nickel-phosphorus coating on a prototype component

Current / On-Going

- Scale and industrialization of process
- Filed patent disclosure
- Continue to optimize the FARADAYIC[®] ElectroDeposition (NiP) process to achieve the desired functional performance
- Design racking and tooling to coat parts provided by FermiLab
- Process prototype Neutrino Focusing Horn segments using the alpha-scale apparatus
- Perform economic (TEA) and scale-up analyses

Acknowledgements

**THANK YOU FOR YOUR ATTENTION!
QUESTIONS?**

Financial support: USAF, DOE

Patent Pending

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